DEMAND-CONTROLLED VENTILATION: AN OUTLINE OF ASSESSMENT METHODS AND SIMULATIONS TOOLS

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ABSTRACT

Enhancing the energy efficiency of buildings imposed by global warming and by the perspective of fossil fuel dwindling requires new technical solutions, more efficient. The race for efficiency directly affects ventilation and air tightness of buildings, the main potential causes of heat loss in homes. If heat recovery is emerging as an effective solution to meet energy performance and indoor air quality in climates with harsh winters, some other solutions appear to be very efficient in moderate climates. The unbalanced demand-controlled ventilation, by adjusting the airflow as to the needs, provides a particularly effective alternative to heat recovery on climatic zones where the difference in indoor-outdoor temperature may not be enough to balance the excess power consumption generated by the heat recovery. Used with humidity control (automatic control of the airflow according to humidity level through a mechanical sensor), unbalanced demand-controlled ventilation system has met a large success due to its simplicity of implementation and operation, especially in the field of social housing where the investment and maintenance constraints are often dominant.

Born in France in the early eighties already in a context of an energy crisis, humidity controlled ventilation has since spread to various countries where it now benefits from a real technical assessment in the regulation. This is particularly the case in Belgium, Spain, Germany and Poland. Different evaluation methods, different tools and assumptions are used according to countries, leading to substantially different results from one country to another. This variety of performance, whether on the energy side or IAQ, finds its origins in various parameters such as regulated airflow rate for reference, outdoor climate, and occupancy modes. This article aims to provide a state of the art of simulation tools, assumptions and evaluation procedure used in different countries to assess DCV. Reference to several studies complement this presentation, such as that conducted by the Fraunhofer Institute in 2009 to compare heat recovery and unbalanced demand-controlled ventilation or the one by Air.H in 2009 to assess the reliability of the simulation tool used in France. This software has been directly compared with actual measurements made on site during a large-scale monitoring in Paris (2007-2009), with very convincing results on the relevance of the calculation algorithm and on the assumptions.

Several tools such as SIREN from CSTB, CONTAM from NIST and WUFi® from Fraunhofer IBP have proven their reliability to assess DCV. Various evaluation methods are now used in different countries, moving DCV and humidity controlled ventilation from innovative to standard. The availability of simulation tools and assessment methods remains essential for all countries wishing to exploit the energy gain potential offered by this technology.

KEYWORDS

Demand, controlled, ventilation, assessment, procedure, model, simulation

INTRODUCTION

Demand controlled ventilation is considered today as a particularly relevant alternative to other efficient ventilation systems such as heat recovery, especially in residential application. With its growing diffusion increases the need for assessing this technology, which requires reliable simulation tools as well as defining precise hypothesis concerning the occupancy, the dwelling characteristics, the weather data and the ventilation components. Different procedures and tools are today used in Europe to assess the energy and IAQ performance of DCV systems. This paper aims at presenting some of the most representative ones, with the application examples of France, Belgium and Germany.

FRENCH APPROACH AND SIREN SIMULATIONS

Regulation and ventilation systems

The French regulation for residential ventilation is defined by a bylaw (“arrêté du 24 mars 1982 modifié le 28 octobre 1983”). The regulation text requires a ventilation system for all new dwelling, natural or mechanical, with a permanent airflow that can be constant or variable according to the demand. Air inlets must be located in the main rooms (bedrooms and living rooms), exhaust is placed in the technical rooms (kitchen, bathroom and toilets). Specific airflows are defined according to the type of dwelling, characterised by the number of main rooms. The regulation requires a minimum value for maximum airflows (see Table 1), and a minimum value for the total airflow (see Table 2) that is agreed only if the demand controlled system is automatic such as the humidity controlled MEV system[1] for example.

Number of main rooms	**Airflows (m3/h)**				
	Kitchen	Bathroom w/wo WC	Other bathroom	WC	
				One	Several
1	75	15	15	15	15
2	90	15	15	15	15
3	105	30	15	15	15
4	120	30	15	30	15
5 and more	135	30	15	30	15

Table 1. Minimum value for maximum airflow according to the number of main rooms.

	Number of main rooms						
	1	2	3	4	5	6	7
Minimum value for total Airflow (m3/h)	10	10	15	20	25	30	35

Table 2. Minimum value for total airflow according to the number of main rooms when using automatic demand controlled ventilation system.

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[1] The humidity controlled MEV system commonly used in France is composed of humidity controlled air inlets and humidity controlled (mixed with presence detection or switch) extract units. The humidity sensor is mechanical, made of polyamide strips.

Assessment procedure and model

The distribution of demand controlled ventilation systems in France is submitted to availability of technical agreements (“avis techniques”) delivered by CSTB. This document not only supplies all the technical requirements, applications, constraints and limits for the system; it validates as well its performance for indoor air quality and energy. The procedure uses the equivalence principle to assess the demand controlled ventilation system: the energy performance of the system is expressed in terms of a constant airflow for each type of dwelling, that is equivalent with the variable one for energy losses. These value can be directly used in the EPB software to assess the global energy performance of the dwelling.

SIREN software has been created by the CSTB more than 15 years ago to assess the IAQ and energy performance of DCV and other innovative ventilation systems in the framework of the Technical Agreement procedure. First used in France, it is currently used to assess demand controlled ventilation in Spain. This dynamic simulation tool offers a calculation method to characterise the aeraulic behaviour of ventilation systems as well as occupants’ exposure to pollutants according to various impacting parameters (see Figure 3).

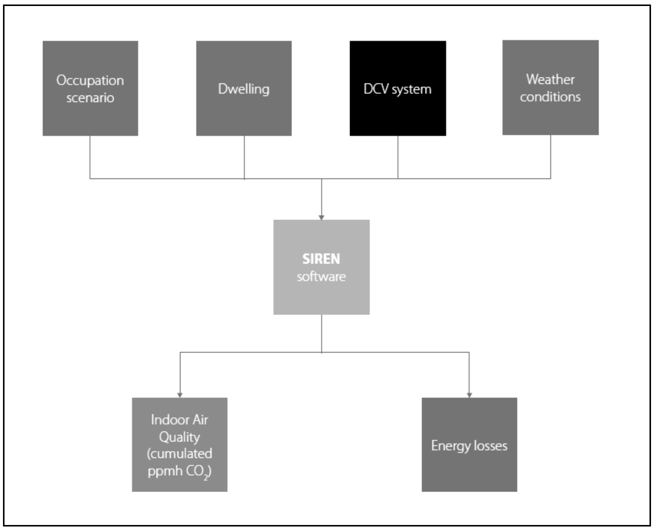
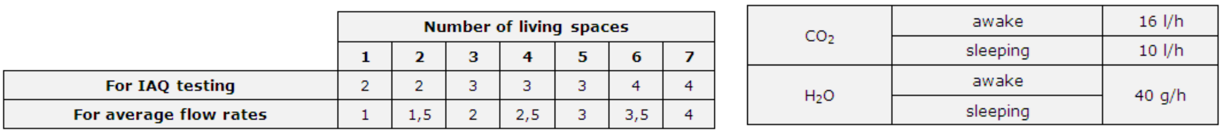


Figure 3. Input and output data for SIREN simulations

The software takes into account numerous factors such as orientation of the dwelling (influence of wind pressures), air leakage, infiltration, location of ventilation components, activity of the inhabitants (through occupation scenario - see Figure 4), adsorption and desorption phenomena, etc. to best mimic the real physical behaviour. A stratification of internal temperatures is also taken into account. The tolerance of the ventilation components must be precisely described to enable the calculation for IAQ (product at the lowest airflow in the tolerance) and for energy savings.



	Number of living spaces						
	1	**2**	**3**	**4**	**5**	**6**	**7**
For IAQ testing	2	2	3	3	3	4	4
For average flow rates	1	1,5	2	2,5	3	3,5	4

CO_2	awake	16 l/h
	sleeping	10 l/h
H_2O	awake	40 g/h
	sleeping	

Figure 4. Base input data for occupation scenarii: Number of occupants according to type of dwelling (left); Metabolism CO2 and H2O production (right).

SIREN computes the indoor air quality (expressed in cumulated CO2 values [ppm.h.]) and the energy losses due to ventilation (thermal losses), expressed as a constant airflow equivalent for energy losses. The ventilation system is validated when the number of hours when CO2 concentration exceed 2000 ppm multiplied by the CO2 concentration during this period does not exceed 500 000 ppm.h. for all the heating season. Several additional parameters such as the number of hours with condensations on windows, numbers of hours with varied humidity ranges, etc. are calculated too, to give a complementary indicative performance result. A data for air sections of demand controlled air inlets is as well given by the simulation tool to be used in the EPB software (influence on the cross-flow ventilation).

Validation of the simulation software

SIREN predictive model has been checked through a large scale experiment in Paris ("Performance de la ventilation et du bâti") in 2009. This monitoring study, carried out on a total of 29 occupied dwellings in two buildings, has confirmed the simulation results with a discrepancy lower than 10%, as showed on Figure 5. The measured results have demonstrated a fairly good reliability of the dynamic tool for energy and aerodynamic simulations. Although SIREN seems to over-evaluate condensation risks (this may be due to some assumptions on room surfaces, doors and windows opening… etc), the software has been proved to be particularly relevant for the evaluation of humidity and demand controlled ventilation systems.

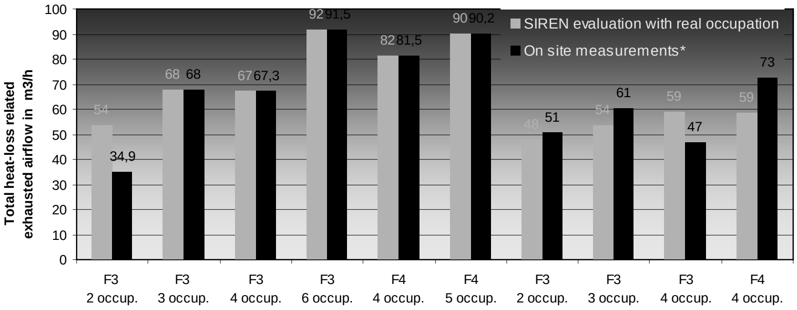


Figure 5. Comparison between SIREN simulations and in-situ measured airflows in the framework of a large scale monitoring ("Performance"). Yearly average heat-losses related airflow per dwelling / occupation type.

From a mono-zone dwelling calculation exclusively designed for MEV, SIREN software is now able to simulate a multi-house building, communicating with an external aeraulic simulation tool to take into account the variable pressure at the terminals. Next developments will allow the calculations in natural and hybrid ventilations; user licences can be bought from CSTB.

BELGIAN APPROACH AND CONTAM CALCULATIONS

Regulation and ventilation systems

In the competence structure of the different state levels in the federal state Belgium, the implementation of the EPB-directive is a regional competence. The Belgian residential

ventilation requirements are set forward in the Belgian Standard NBN D 50-001, which is annexed to the EPB-decrees of the different regions. This standard dates back from 1991 and in it, the ventilation systems are presented in a descriptive manner. 4 standard systems are described, ranging from natural ventilation (system A), over simple exhaust (system C) or supply ventilation (system B) to fully mechanical ventilation (system D). In the market, systems A, C and D are dominant, while system B is virtually inexistent.
The standard requires the air supply and return components of the systems to be sized according to the function of the room in which they are located. These required design flow rates are listed in Table 6. Non-mechanical components such as trickle ventilators and transfer grilles are to be sized to this flow rate at a reference pressure drop of 2 Pa.

Since the standard only mentions demand control as a possible extension of the reference systems without any detail as to how this demand control should be achieved, an equivalence approach is used to rate the performance of demand controlled ventilation systems. This assessment is done by UBAtc, a technical approval agency in Belgium and is valid for all the regions. In order to be deemed equivalent to the reference systems in the standard and therefore acceptable under the building code, the performance of the demand controlled system can not be inferior to the worst performance obtained by the application of each of the reference systems.

room	minimum	Limited to:
living	1 l/s/m^2 > 21 l/s	42 l/s
Sleep/office	1 l/s/m^2 > 7 l/s	20 l/s
Kitchen, storage, bathroom	1 l/s/m^2 > 14 l/s	21 l/s
WC	7 l/s	
Open kitchen	> 21 l/s	

Table 6. Design flow rates in the Belgian residential ventilation standard NBN D 50-001

Simulation tool and parameters

A demand controlled residential ventilation system is assessed through numerical simulations with the multi-zone airflow model Contam, developed by NIST. The uncertainty associated with different implementations of the system under review in specific dwellings is taken into account by applying a Monte-Carlo algorithm, varying such parameters as occupancy, environmental conditions and building orientation. The distributions of these parameters are based on available data from the Belgian statistics institute. 100 sample sets are used. Other parameters such as system characteristics, building leakage level and geometry and indoor temperature are fixed at different intervals. This amounts to over 1000 simulations for each system or variant of a system. The simulations are run over the typical heating season in Belgium for a moderately insulated dwelling. Both the system under review and the 3 reference systems that have a reasonable market share are assessed.

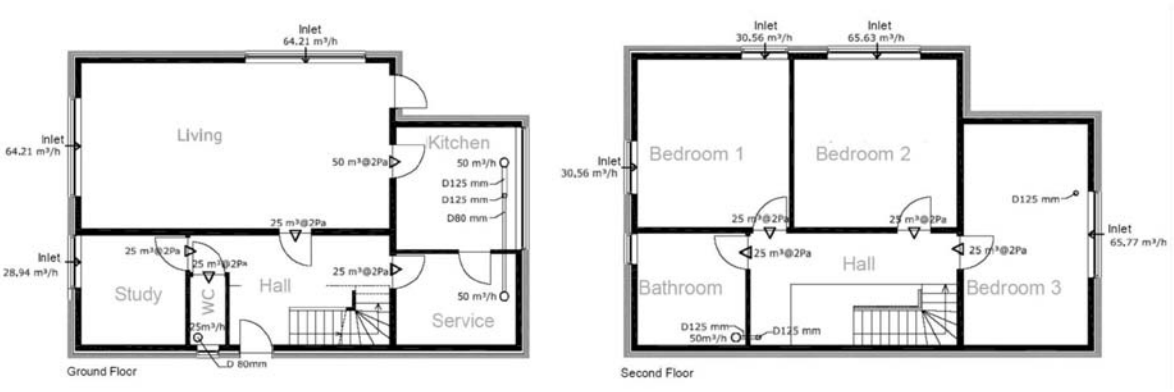


Figure 7. Geometry of the reference building used in the equivalence procedure.

The performance of the demand controlled system is assessed on 3 IAQ parameters, namely humidity level, exposure to odours (tracer) and perceived indoor air quality (carbon dioxide). If performance of the system under review is equal to that of the worst performing reference system for each of these parameters, it is accepted as equivalent and an energy saving coefficient is determined.

The level of IAQ that is attained by the application of the system is taken into account to determine the energy saving coefficient. The coefficient is defined as the ratio of the heating season integrated ventilation heat loss with the exclusion of infiltration losses and a reference. This reference is determined by interpolating between the heat loss levels of the 2 reference systems from the standard (A, C and D) that produce an IAQ level just higher and lower respectively than the system under review, based on the IAQ level attained by the latter system. The process for the determination of the reference and the energy saving coefficient for a system ‘X’ demonstrated in Figure 8.

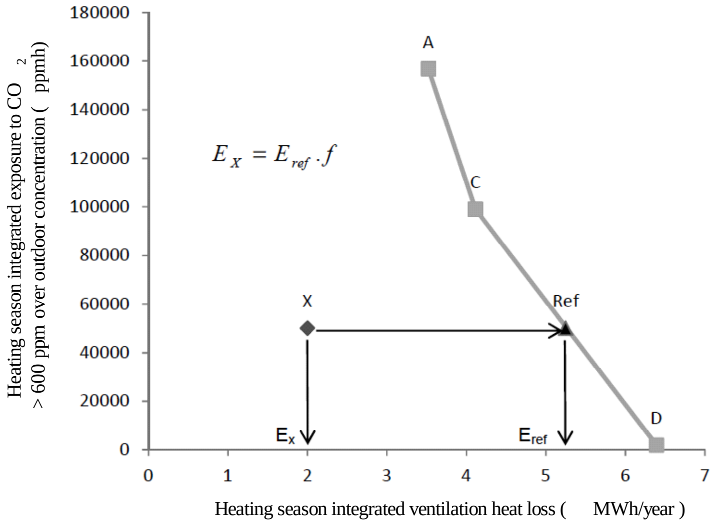


Figure 8. Reference and energy saving coefficient calculation for a ventilation system X

The infiltration heat losses are treated separately in the EPB-calculation method. Nevertheless, should the building leakage to infiltration heat loss ratio obtained under operation of the demand controlled system be different from that of the reference systems, an additional correction coefficient for this is calculated. So far, however, no system reviewed presented such behaviour.

COMPARED PERFORMANCES OF A HUMIDITY CONTROL MEV AND A BALANCED HEAT RECOVERY IN GERMANY USING "WUFI® PLUS" SIMULATION TOOL

Study

If Germany does not propose technical agreement for assessing DCV as it is done in France, Spain and Belgium, several studies have been realised using comparable simulation tools and methodology. A study conducted in 2010 by the Fraunhofer Institut Bauphysik IBP has consisted in simulating the working of two ventilation systems on a single-family house: on one hand, a demand controlled (humidity controlled) exhaust MEV system which varies the air changes depending on the relative humidity in the room and, on the other hand, a standard supply and exhaust system with a constant air change rate of 0.4 ACH and an integrated heat recovery. The heat recovery efficiency of this unit is of 93% according to its manufacturer with additional electrical preheating device. The comparative calculations has been carried out for both ventilation systems for a new built house with high insulation (according to DIN V 4108-6:2003 and DIN EN 12831-Bbl. 1) with a heated and ventilated living area of 205.6 m2 and a ventilated volume of 534.6 m3. The heat transfer coefficient of the outside walls is 0.25 W/m2K, with the roof at 0.18 W/m2K and the ground floor at 0.7 W/m2K. The windows have a U-value of 1.1 W/m2K. The reference cold city of Hof (Germany) has been selected as for the weather data. The indoor temperature is 20° C.

Simulation software

The evaluation of the various ventilation systems has been made possible by the newly-developed hygrothermal indoor climate simulation model WUFI® Plus. This last belongs to a larger software family which allows realistic calculation of the transient coupled one- and two dimensional heat and moisture transport in multi-layer building components exposed to natural weather. It is based on the newest findings regarding vapour diffusion and liquid transport in building materials and has been validated by detailed comparison with measurements obtained in the laboratory and on IBP's outdoor testing field. The sofware is available at Fraunhofer IBP.

The study, that has simulated two years working, has supplied a complete comparison between the different ventilation systems in termes of energy performance, separating heat losses from electricity consumed by the fan(s) and for the preheating (see result on Figure 8). It has demonstrated –notably- the low difference between humidity controlled MEV and balanced system (HR) with 93% heat recovery. WUFI® Plus enabled also to check the indoor air quality through the recording of CO2 concentration, according to different occupation scenarii.

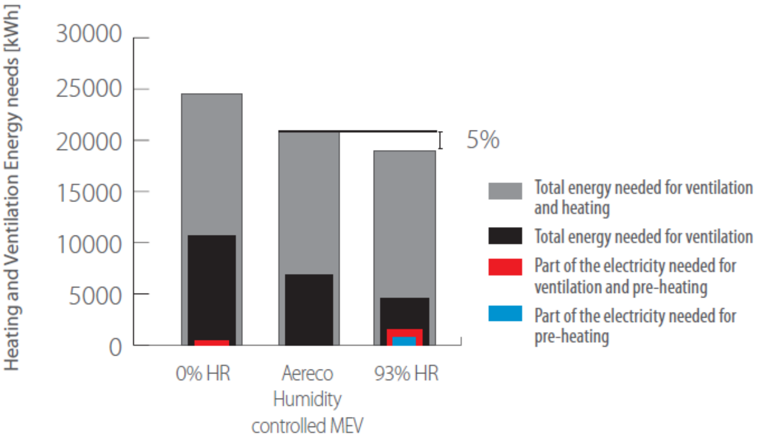


Figure 8. Total energy consumption of various compared ventilation systems

CONCLUSIONS AND PERSPECTIVES

Defining adapted assessment procedures and identifying reliable simulation tools is a crucial point to take into account demand control ventilation systems in the EPB regulations. Several procedure and simulation tools such as SIREN (CSTB), CONTAM (NIST) and WUFI® Plus (Fraunhofer IBP) for example are today used in different countries such as in France, Spain, Belgium and Germany to assess the energy and IAQ performance of DCV systems. We could cite as well studies realised in Switzerland and in Poland (through NAPE), demonstrating the strong interest and need for proposing an assessment of DCV systems.

If parameters and hypothesis must be adapted to the software, to the regulation and to specific conditions, all available simulation tools have proved their reliability, notably by comparison with laboratory or in-situ measurements. From MEV only, new developments are today being carried out to widen the application field, for hybrid and natural ventilation notably.

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